

Integrated Boundary Current Observations in the Global Climate System

U.Send, R.Davis, D.Rudnick, P.Niiler, B.Cornuelle, D.Roemmich

Collaborators: S.Gille, N.Schneider, W.Kessler, S.Bograd

Scripps Institution of Oceanography, La Jolla, CA

Project Summary

The current national and international ocean observing system for climate consists of several components, none of which are designed for capturing intense, concentrated, or deep circulation systems. Therefore, additional approaches and infrastructure are needed for observing western and eastern boundary currents, throughflows/overflows, and deep circulation regimes.

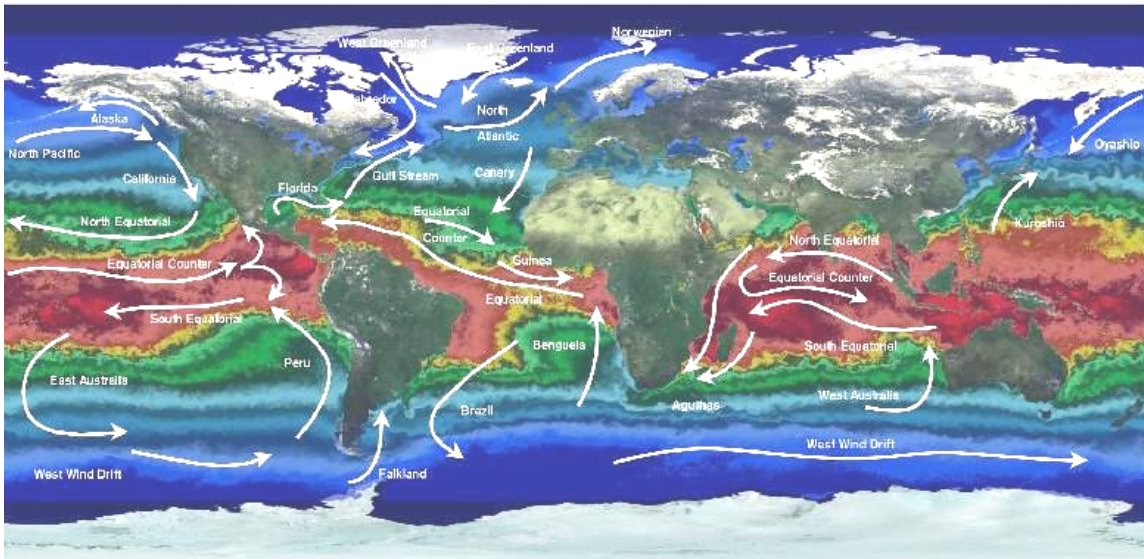
We propose to develop, demonstrate, and implement a system that can fully monitor the intensity (mass and heat transports) of most boundary currents in a sustained and routine mode, delivering indicators about the state of those regimes in near-realtime. To this end we will merge several technologies and techniques that have been used by the P.I.'s in the past, and that were partly developed in prior CORC phases. These include

- *end-point moorings* (with CTD sensors throughout the water column and bottom pressure sensors) at the ends of a section to determine the dynamic height difference, and thus geostrophic transports, as a time series.
- *underwater gliders* to estimate the heat transport through a section, by providing the horizontal (and vertical) distribution of heat content and its correlation with the flow.
- *inverted echosounders plus bottom pressure (PIES)* distributed along the section to be monitored. These will yield 2 vertical integrals (e.g. dynamic height and heat content) at each location, providing the depth (and time) coverage along the section that the gliders can not.
- *data telemetry* for the PIES and (subsurface) moorings using acoustic modems between these and the gliders. In very high (surface intensified) current regions, the gliders may need to remain submerged on one of the round-trip crossings each time. In this case, a navigation capability will be needed in the gliders to pass within close enough proximity of the PIES and moorings.
- *data assimilation* for determining heat and flow distributions, and thus the full mass and heat transports, that are consistent with all the data types collected, with satellite altimetry, with the forcing fields (wind) and with up/downstream and offshore information.

The pilot and testbed application will be carried out in the California Current which has large climate and socio-economic relevance and does not have a routine monitoring system. Operation along CalCOFI line 90 in southern California assures synergy with other programs, and coincides approximately with the high resolution XBT line PX31 which will contribute comparison data and connect sampling to the basin interior. In addition automated surface drifter releases will quantify the eddy variability and the Ekman flow in the boundary current region.

Later in the project, implementation of the system in the climatically highly relevant western boundary current of the low-latitude western Pacific is planned (which feeds the Equatorial Undercurrent through the Solomon Sea).

FY 2007 Progress



Task A: Glider Operations in Boundary Current Observing Systems

(Russ E. Davis and Daniel L. Rudnick)

Gliders play two roles within our program to develop techniques for monitoring western boundary currents. In the eventual array, gliders will quantify shallow transport through the section of interest while interrogating deep instrumentation and relaying that data by satellite transmission. While the array technology is being developed and tested, gliders are exploring the western boundary flow toward the equator in the South Pacific where the Boundary Current Array may first be tested. During FY07 we have made good progress on two glider tasks: (1) reconnaissance of the main flows toward the equatorial zone in the western South Pacific and (2) development of an acoustic communication capability for Spray gliders so they can relay to shore data from subsurface instrumentation that has no surface expression.

South Pacific Reconnaissance

The equatorial Pacific is a key climatic region because it is where upper ocean temperature is well enough coupled to the atmosphere that variation of ocean heat content trigger substantial atmospheric interannual variability. While significant predictive skill has been achieved, predictability of equatorial atmospheric variability could potentially be increased if the internal oceanic factors influencing equatorial SST variability were better understood. A majority of the water that feeds the equatorial undercurrent, and thus provides the source waters for equatorial upwelling, comes from the South Equatorial Current (SEC). The SEC feeds the western equatorial zone through complex and poorly understood pathways in the western tropical Pacific including the New Guinea Coastal Current and associated pathways through the Solomon Sea as depicted in Fig. 1. This western boundary complex is a potential target for the first use of the Boundary Current Array technology being developed by CORC.

The reconnaissance task for the Pilot Array addresses the poorly observed connections of the SEC to the equatorial zone using Spray gliders to measure upper-ocean transport in the region and potentially to measure variability of the mass and heat transport between the SEC

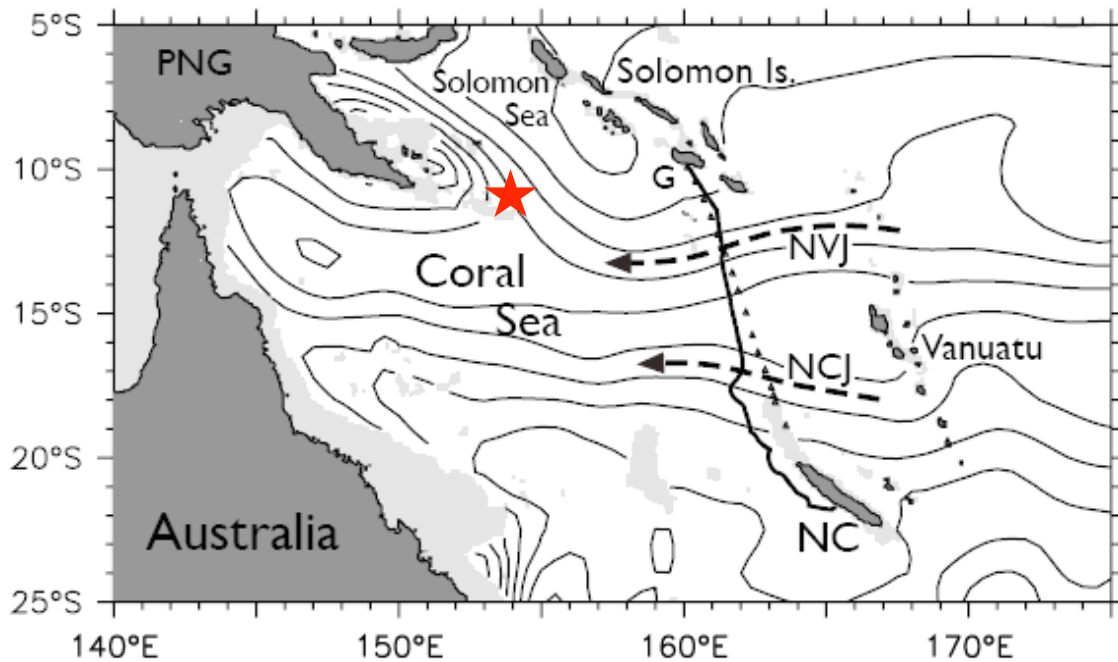


Figure 1: The Coral and Solomon Seas showing mean flow on the $\sigma_\theta = 25.5$ surface (line contours) and the major land masses (NC=New Caledonia, G=Guadalcanal, the Solomon Islands, and PNG=Papua New Guinea). NCJ and NVJ indicate jets in the South Equatorial Current. The Solomon Sea is the main pathway of this flow to the equator. The line from New Caledonia to Guadalcanal is the path of the first glider crossing. The red star marks the position at the eastern end of the New Guinea continental shelf where a glider was deployed to cross the Solomon Sea to Guadalcanal.

and the equatorial zone. These gliders cycle vertically between the surface and a depth between 500 and 1000 m. They directly measure horizontal velocity averaged over their operating depth by comparing dead reckoning and actual positions. By measuring temperature and salinity sections, they also measure geostrophic shear which can be referenced with the depth-averaged velocities.

In the reporting period, we have (1) completed and had accepted a paper describing our first glider measurements of the SEC between New Caledonia and Guadalcanal; (2) recovered a second transit from Guadalcanal to New Caledonia; (3) recovered in the Solomon Islands a glider that had crossed the Solomon Sea from New Guinea exploring the potential for gliders to monitor flow toward the equator through the Solomon Sea, and (4) deployed another glider intended to transit from Guadalcanal to New Guinea and return to Guadalcanal

This effort is aimed finding a practical way to monitor mass and heat transport from the SEC to the western equatorial zone where it feeds, and potentially modulates, the thermocline waters that upwell in the equatorial zone, influencing equatorial SST and air-sea coupling in the ENSO cycle. This is a collaboration between SIO (which is responsible for gliders), William Kessler of PMEL (who provides modeling and theoretical expertise), and Lionel Gourdeau of IRD in Noumea (who directs South Pacific operations carried out largely by IRD personnel).

Our first glider section, completed in October 2005, was between Guadalcanal and New Caledonia (the solid line in Figure 1). The results, including confirmation of model-predicted jets near both Guadalcanal and New Caledonia, are reported by Gourdeau, L., W.S. Kessler, R.E. Davis, J. Sherman, C. Maes and E. Kestenare in “Zonal jets entering the Coral Sea” now in press at the *Journal of Physical Oceanography*. The glider measured SEC transport above 600 m (32 Sv) compared well with a hydrographic section taken when the glider section began. We regarded this

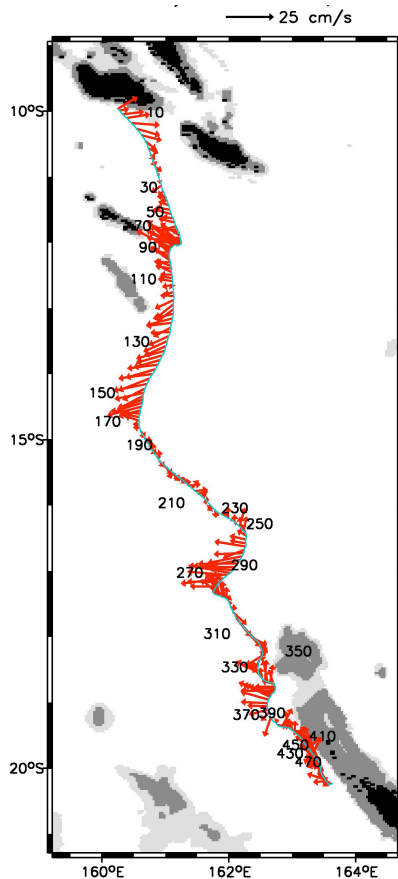


Figure 2: Trajectory (green line at the base of arrows) and depth-averaged velocity from the surface to 600 m depth (red arrows, scale at the top of the figure). The cruise began in Guadalcanal (north end) on 12 Nov 2006 and was recovered with fish-attack damage in New Caledonia on 1 Mar 2007. Velocities are unreliable after Dive 168 because of fish attack damage to the glider.

as a successful demonstration of the capability of gliders to measure, and eventually to monitor, such shallow transport.

A second glider was deployed near Guadalcanal in November 2006 and piloted to New Caledonia. Halfway through the transit, while operating well below the surface, Spray 01 was hit/bitten hard enough by something that its attitude and depth were upset and it could not subsequently maintain its cruising speed; this also made subsequent velocity measurements inaccurate (after dive 168 in figure 2). Further into the mission, the CTD salinity underwent a sudden step change of $O(0.1)$ at the same time that attitude and depth records indicate another attack. On recovery, part of the tail was missing and there were coarse abrasion marks on the glider's wings and hull, clearly indicating fish attacks. Like measurement errors caused by bio-fouling, attacks by marine predators are intrinsic to autonomous sampling and, although rare, constitute a real operational factor. The reliable data (north end in Fig. 2) shows weaker westward flow in the SEC that in October-December 2005 cruise but similar jet structure

A third Spray cruise shifted focus from the SEC south of Guadalcanal to the pathways toward the equator through the Solomon Sea. On 18 August 2007, Spray 06 was deployed near Rossel Island (the eastern tip of the New Guinea continental shelf) to cross the Solomon Sea to Guadalcanal. Because so little is known about circulation in this area, the initial crossing, depicted in Figure 3, was used to explore transport pathways through the Solomon Sea.

After observing flow into Mile Bay north of the Louisiade Archipelago and crossing the main western boundary current near Laughlin Island, Spray 06 crossed the Solomon Sea to the vicinity of Bougainville Island and then began working south eastward toward Guadalcanal making repeated crossings of a suspected eastern boundary current. At this point the glider's pitch sensor apparently failed (we have not yet received the glider for post mortem) and it was piloted to an emergency recovery (carried out by W. Kessler and scientists from IRD). Another glider was deployed from

Guadalcanal for transit to Rossel Island and a return to Guadalcanal. Similar operations will continue through most of 2008 seeking to learn enough about the paths for SEC flow toward the equator to site the full-scale Boundary Current Array.

Although the problem that interrupted the Solomon Sea crossing cannot be diagnosed until the glider is back in the laboratory, we are concerned that it was caused by a glider equipment failure. We are planning a complete reliability review of Spray's past performance and intend to identify the subsystems most in need of improvement. The possibility of redundant subsystems (like the compass – level), replacement of unreliable components, and improved testing will be weighed against the associated increased operating cost and the cost of failed missions. In

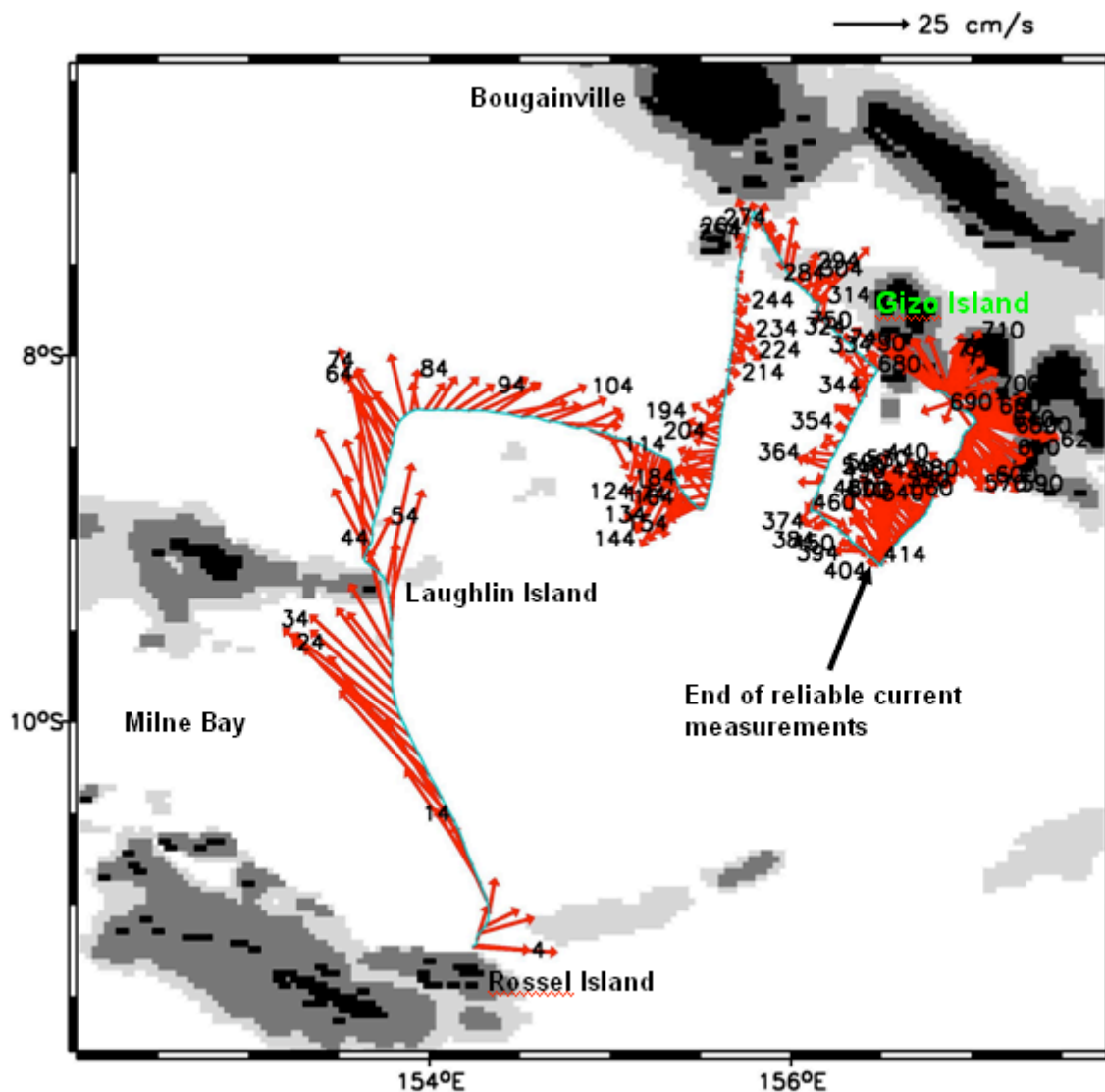


Figure 3: Trajectory of Aug-Nov 2007 glider crossing of the Solomon Sea (green line) and measured depth-averaged currents (red arrows). Rossel Island is at the tip of Louisiade Archipelago, which extends east from New Guinea. The archipelago blocks flow of the SEC into Milne Bay. The strong observed flow into Milne Bay shows that flow out of Milne Bay toward the New Guinea coast is not so thoroughly blocked. Near dive 410 (black arrow) the glider's pitch sensor failed and velocities become unreliable. The mission was aborted and the glider recovered near Gizo Island.

remote sites, like the Solomon Sea, the cost of failures is increased and an increased level of reliability may be cost effective.

Acoustic Communication Glider

An essential element of our Boundary Current Array is using an acoustically transponding glider to interrogate subsurface instrumentation with no surface expression to support data relay and to then carry the data to the surface for relay by Iridium satellite. During the reporting period, we designed, constructed, and tested an acoustically transponding Spray glider. A Spray was modified to slightly increase its volume to support a Benthos ATM-885 modem which operates at 11-13 kHz. Electronics are mounted inside the Spray hull and the transducer is mounted in the tail (where an ADCP is sometimes fitted) with the transducer facing downwards. Aside from a slight increase in

mass and length, the acoustically transponding glider is a normal Spray capable of measuring high resolution temperature and salinity sections and depth averaged currents.

The acoustically transponding Spray was tested on 14 November when it was operated in 900 m of water within a kilometer of the PIES mounted on the bottom. Although tests between the PIES and a shipboard modem indicated that communications should be reliable at 1200 baud, we operated the PIES-Spray acoustic link at a much more conservative 140 baud speed. With Spray floating at the surface and free of the ship, Spray interrogated the PIES and successfully received the entire PIES data record of 2420 bytes. The PIES data was then relayed through Iridium to our laboratory where the data agreed with the data recorded internally in Spray. The PIES data message has embedded checksums and from which it was determined that the data received acoustically contained 2 single-bit errors. Spray then performed a dive to 100 meters during which it interrogated the PIES during ascent. This data was relayed to shore via Iridium, along with a CTD profile and GPS fix, once Spray reached the surface. The relayed data contained no errors and once again the Iridium data agreed with data stored in Spray. An attempt to establish communications at a horizontal distance failed; acoustic ray-tracing indicated no paths connecting the PIES to the glider depth.

The limited testing to date is little more than a check against significant errors and there is substantial software work needed to integrate acoustic communications into the mix of Spray operations. However, we have met the major milestone of a freely diving glider establishing communication with a PIES on the seafloor, downloading its data acoustically, and then relaying the PIES data to shore once at the surface. More is shown under task B.

Task B: Moorings and PIES in Boundary Current Observing Systems (U.Send)

The main goal in the reporting period was the development and initial testing of the fixed instrumentation needed to implement the proposed boundary current observing system. After researching the available options and choosing an acoustic modem type (Teledyne Benthos ATM-885), several of these modems were purchased, with and without pressure case (OEM version), for attachment to an inverted echosounder with pressure sensor (PIES) and to the moorings, and also for incorporation into a glider (see task A).

A hierarchy of modifications of the PIES instrument was designed and agreed on with the manufacturer (Univ. of Rhode Island, URI), for attaching and later incorporating the acoustic modems to/into the PIES. This requires diverting some of the internal data streams to an extra

line/port going to the acoustic modem, and the first stage of this was also implemented with the manufacturer. The present configuration of the modified PIES with an external modem attached, is shown in the foto in figure 4.



Figure 4: Assembly of the modified PIES (white sphere) with an external modem (black cylinder), mounted onto a

stable bottom tripod (together with extra buoyancy, yellow sphere).

After testing the modem extensively in the lab, measuring the power consumption and the communication capabilities (see technical annex in previous year report), the system was deployed in 900m of water depth off San Diego in October 2007, on the inshore end of the CalCOFI line 93, see figure 5 (the real implementation in year 3 will take place offshore on line 90). Communication was then established from the boat to the modem-PIES assembly, by lowering a second modem over the side to a depth of a few meters. Successful communication was possible to a distance of about 6km, see figure 6 showing the SNR ratio as a function of distance. Beyond 6km, a shadow zone exists at the surface (see figure 7), and we believe longer ranges will be possible at larger depths.

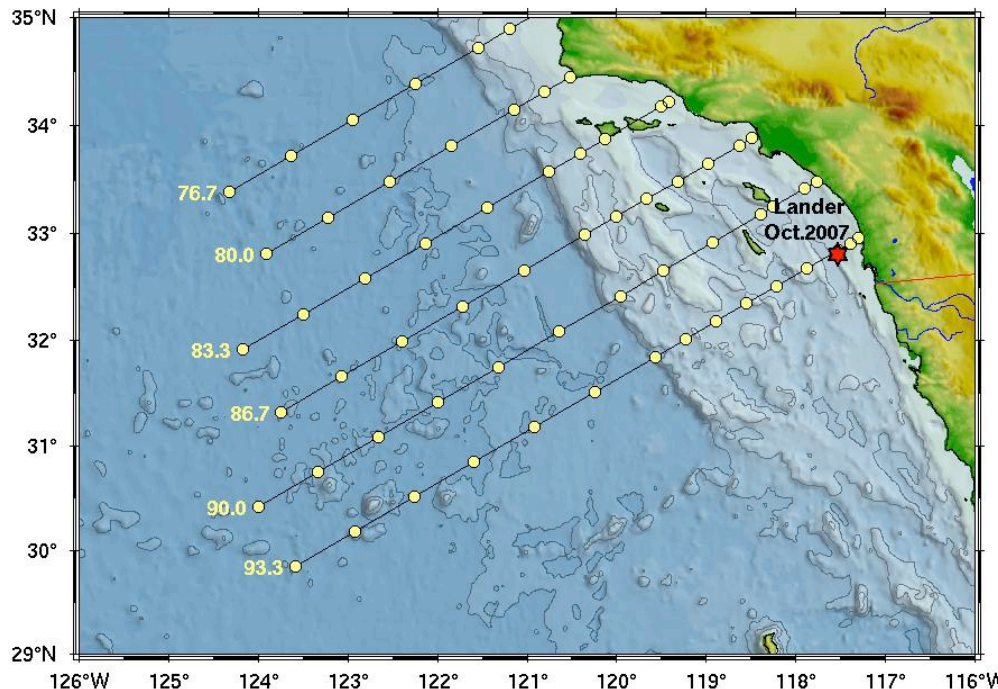


Figure 5: Location of the test deployment of the modem-PIES assembly off San Diego, in 900m water depth (red asterisk). Also indicated for reference is the CalCOFI sampling grid, from line 93 (south) to line 76 (north).

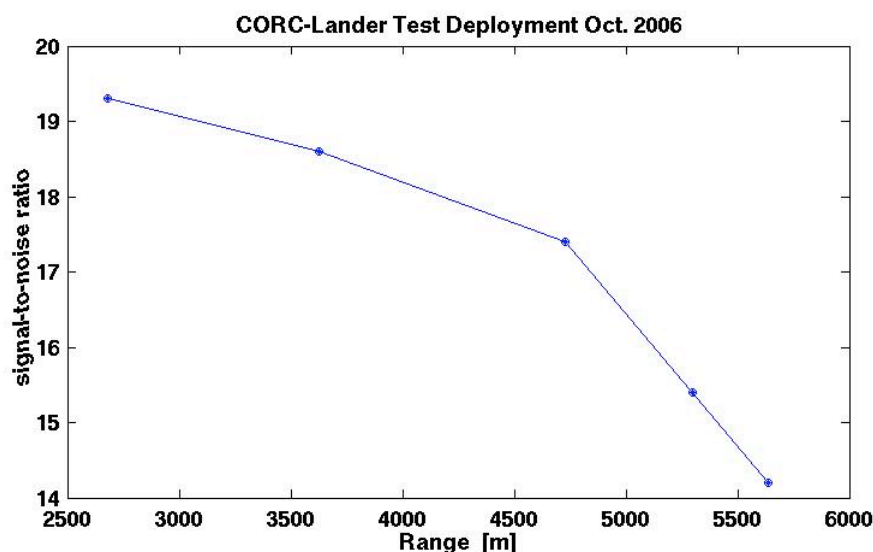


Figure 6: Signal-to-Noise ratio measured with the modem during test transmissions between the boat and the PIES modem. A range of close to 6km was achieved.

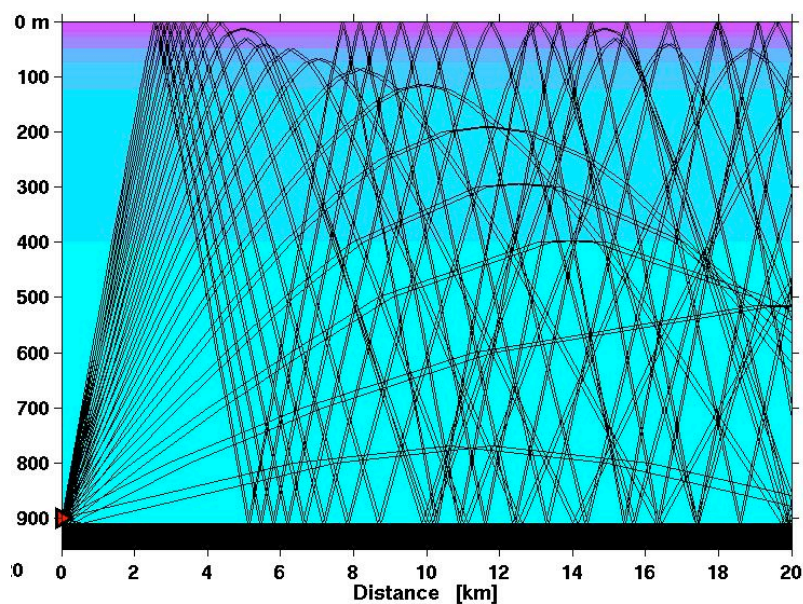


Figure 7: Raytrace calculation for acoustic propagation paths emanating from the PIES on the bottom. Beyond about 6km distance there are no more paths to the surface, i.e. a shadow zone exists (color shows sound the speed stratification).

In mid-November, first tests with the glider were carried out to communicate acoustically with the bottom-mounted PIES deployed at the above location. By that time, the PIES had accumulated 5 weeks of daily average traveltimes and bottom pressure values (future versions of the CORC PIES will telemeter single ensembles of these measurements as well). Figure 8 shows the transponding glider prior to the dive (described under task A), figure 9 shows a short water column heat content timeseries derived from the telemetered traveltime data.



Figure 8: The first CORC Spray glider equipped with the acoustic modem (transducer mounted in the white rear section) prior to test deployment near the bottom-mounted PIES.

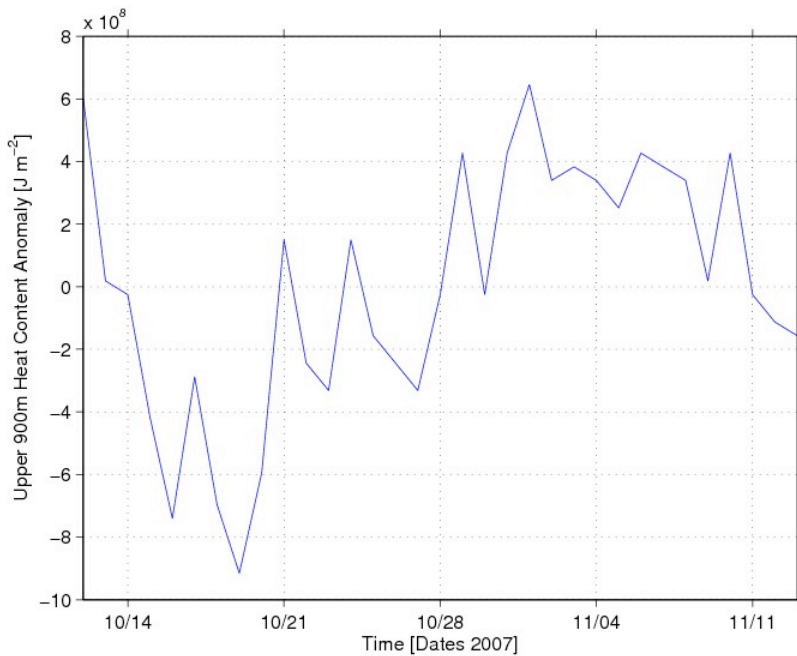


Figure 9: Vertical water-column heat content derived from the daily average acoustic traveltimes between the PIES and surface. This kind of data will be an important part of the CORC sampling strategy.

Order for the final PIES have been placed now, which will bring the total number of CORC PIES with the modem capability to six. We will need to purchase additional modems now, after the successful tests, in order to have 6 functional PIES ready for deployment on CalCOFI line 90 for the coming year. In parallel, preparations are being finalized now for deployment of a test *mooring* in the vicinity of the PIES shown above. A controller is nearing completion, which will be installed in the mooring, collecting data inductively from T/S microcat sensors and passing these to a Benthos modem in the mooring, for telemetry to a glider. This mooring is planned to be deployed before the end of the year.

Task C: XBT data in support of the California Current observing system (D.Roemmich)

Main task: Analysis of High Resolution XBT transects in the California Current system

The High Resolution XBT Network (HRX) collects eddy-resolving temperature transects along commercial shipping routes. Most lines are sampled on a quarterly basis, with temperature profiles from 0-800 m at horizontal separations ranging from 50 km in mid-ocean to 10 km near ocean boundaries. Two HRX transects cross the California Current system (Fig 1). These are lines PX37 (San Francisco-to-Honolulu) and PX31 (Los Angeles-to-Fiji). The latter is in close proximity to CalCOFI Line 90. Line PX37 has been sampled continuously since 1992.

Analysis of HRX data from PX37 and PX31 (Fig 10), including temperature, salinity, and geostrophic velocity and transport, will allow the more intensive CORC measurement program along CalCOFI Line 90 to be placed in the context of the larger eastern subtropical North Pacific domain.

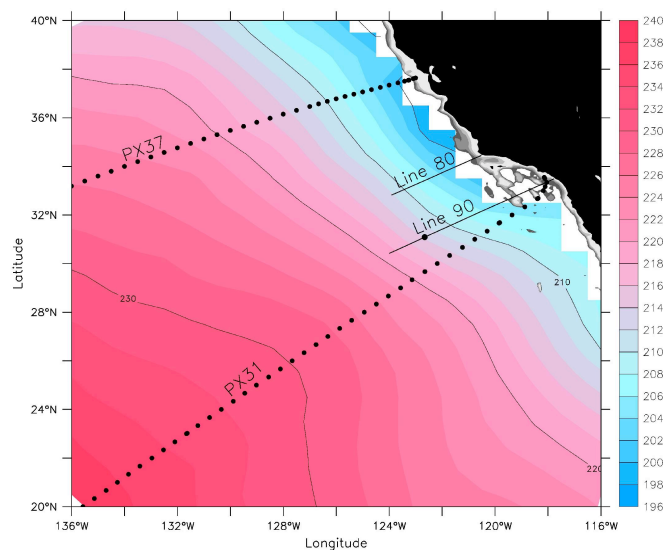
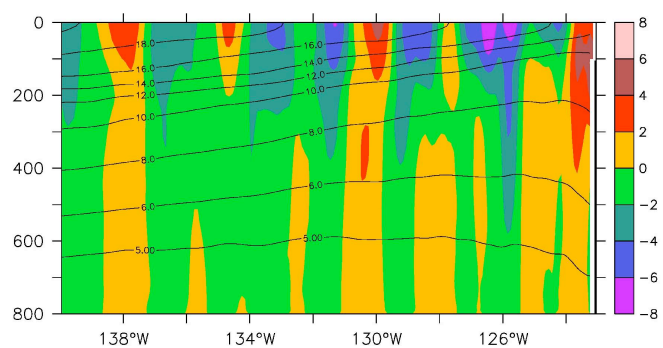


Figure 10:

(TOP) HRX Lines PX37 and PX31 are shown in relation to CalCOFI Lines 80 and 90, and to the mean dynamic height of the sea surface from Argo (0/2000 dbar, 2 dyn cm shaded intervals). Station 90.100 is marked as a dot on Line 90.



(BOTTOM) The 60-cruise (15-year) mean geostrophic velocity across HRX Line PX37.

Accomplishments:

Work began only recently on this project, and to date has consisted of organizing the individual datasets (HRX P37 and P31, CalCOFI Line 90, Argo), calculating geostrophic velocity and volume transport integrals. Fig 11 shows transport integrals from the shoreward-most station on CalCOFI Line 90 out to Station 80 and to Station 100 (see dot on Fig 10 Line 90). It is clear that substantial southward extends beyond Station 80 and that there is large variability in Line 90 transport.

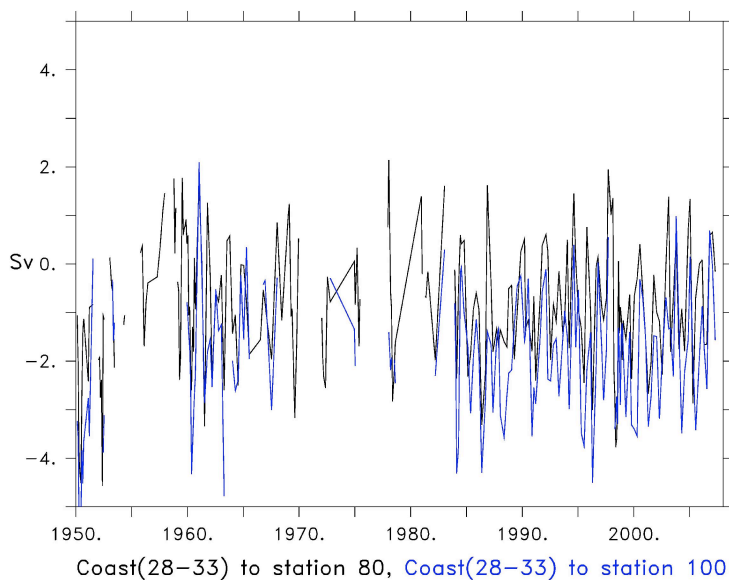


Figure 11: Geostrophic transport (0-500 m) across CalCOFI Line 90, integrated from shore out to Station 90.80 (black) or 90.100 (blue)

Add-task: Evaluation of 2000 m (LMP5-T1) XBT for ocean boundary current and ocean interior sampling

Present sampling with expendable bathythermograph (XBT) probes at high ship speeds is limited to 800 m. A new XBT probe (LMP5-T1) is under development by Lockheed Martin Co (formerly as Sippican Corp) to provide research-quality temperature versus depth measurements to 2000 m at ship speeds of 20 knots. The HRX program is assisting this development by testing prototype LMP5-T1 probes.

We planned to deploy approximately 240 LMP5-T1 probes, and to evaluate their potential for use in the HRX Network.

If the effectiveness of the LMP5-T1 could be demonstrated, combining it with Deep Blue XBT and Argo float data would have widespread usage in the HRX Network for ocean circulation and heat transport estimation.

Accomplishments:

Development of the LMP5-T1 probe by Lockheed Martin has been delayed by integration of pressure point calibration circuitry into the instrument. We have elected not to take delivery of probes without the pressure point. The work will be initiated as soon as probes can be built. No new funds are requested.

Task D: Analysis of CALCOFI, Drifter and Altimeter Data for Climate Evolution Modes (Peter Niiler and Yoo Yin Kim and Luca Centurioni)

The CalCOFI hydrographic grid off the southern California coast was sampled on a yearly to seasonal basis from 1949 to 2007. These data, when taken together with drifter (1985-2007) and altimeter data (1992-2007) can be used to define a variety of “interannual-to-decadal modes” of variability. For example, a “mode” of mass transport can be constructed from smoothing the data with several energy containing EOFs of the time average space correlation matrix of monthly anomalies of geostrophic velocity relative to 500m at Line#90. From this “smoothed” spatially coherent data of velocity, a climate mode of variability can be constructed by filtering the time series at each location.

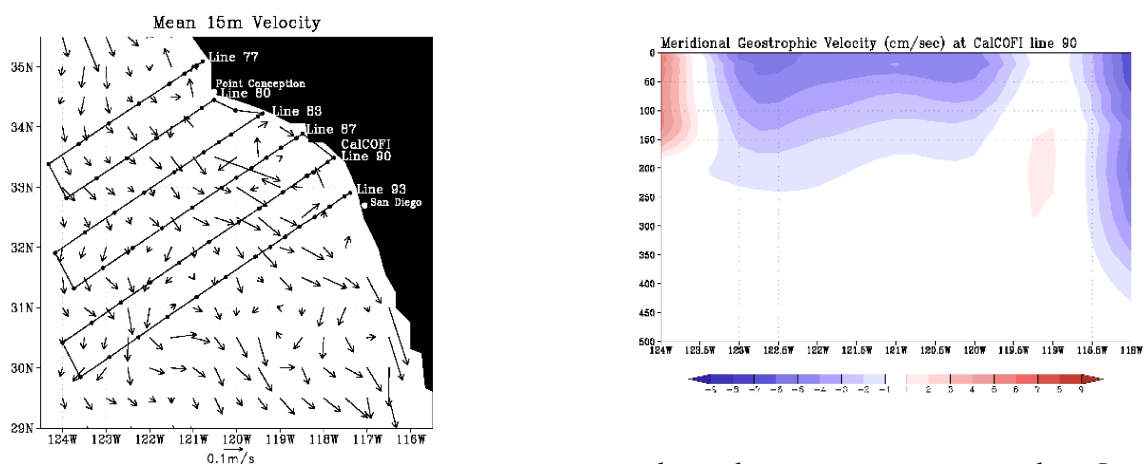
The Schneider et al. (2005) used the CalCOFI Line #90, data from 1937-1999 to demonstrate the differences in the temperature and salinity modes of long time-scale variability. The temperature variability in and above the seasonal thermocline was largely related to ENSO. But the salinity variability, which could not be related directly to either ENSO or the PDO, was produced by time variations of long-term persistent transport features that advected anomalous water masses across Line #90. Since this calculation was made, there now are 8 more years of CalCOFI hydrographic data.

We propose to analyze the complete CalCOFI hydrographic data set for coherent patterns of relative geostrophic circulation from 1949-2007 and calculate how these relate to the altimeter (1992-2007) and drifter observations (1985-2007). The principal objective is to construct an interannual-to-decadal mass, thermal energy and property transport indices for the area that is to be sampled by the CORC moored/gliders array and modeled by the CORC California Current climate model.

The following specific tasks form the initial basis of our analysis. Progress is noted in *italics*:

1. Organization of quality controlled data file. This task requires the organization of the historical CalCOFI hydrographic, the Global Drifter and the AVISO altimeter files. Most of these data are available on existing files but require additional quality control and assembly into joint files for analysis. *This task has largely been completed for the hydrographic and drifter data sets in the 2006-2007 funding period (viz. Fig. 12).*
2. Computation of the principal, spatial coherent modes of variability. A variety of programs exist for this computation, especially when different engineering units are used designate the files (e.g. temperature, salinity, velocity, dynamic height, etc.). We will rely on the expertise of the CORC Investigators to recommend the appropriate analysis tools. *This task has been initiated for hydrographic data but the velocity and sea level data has not been included because these are available over the past 13-15 years.*

Figure 12. The 15m velocity derived from 0.5° ensemble averaged drifter data in the CalCOFI region (left panel; for methodology, viz. Niiler 2001) and the



geostrophic velocity component normal to Line#90 as function of depth and longitude along Line#90 (right panel). Because significant differences exist at in these distributions at 15m depth along Line#90, the challenge is to determine how these two data, and others named above, can be used to derive the absolute, depth dependent circulation, and its variability, from the historical data in the CalCOFI area.

3. Release of SVP drifters on Quarterly CalCOFI cruises. Our proposal was to commence the releases in July 2007 with 7 SVP drifter deployments on each of the CalCOFI cruises. The velocity observations from these will be used to aid in the definition of the circulation patterns in the area of the CORC CCS monitoring. The Global Drifter Program will supported these releases as part of the global deployment of drifting buoys. *The plan is to begin releases of drifters in the CalCOFI survey in winter of 2007-08.*

Add-Task: Development of Autonomous Deployment Pods for Drifters

The objective of this task is to design, test and deploy autonomous drifter release containers for sampling of ocean boundary current systems. A package, containing 5-10 drifters with borosilicate

glass floats would be placed on the ocean floor from which periodic releases to the surface would occur. The technology for the release mechanism has been designed, tested and deployed by several oceanographic laboratories (WHOI, U.R.I, etc). We anticipate adapting a 'burn wire' methodology, in which drifters are packed into and released from a cylindrical 35cm x 2m tube that rests vertically on the ocean floor. The principal technical issues are to construct the release mechanism that is fit into the tube on the bottom and to package the drifters into a compact form. For the latter purpose, the drogue shape will be altered into a truncated cylinder that allows the surface glass float and the coiled tether to nest in a vertical space that is about 50 cm in the vertical. In summer of 2008, the sea tests will commence in progressively deeper water, beginning in 15m water depth off the Scripps Pier (scuba diving depth) and culminating in 1000m in the San Diego trough in late 2008. Deployment in the CORCIII observation area and, anticipating future deployments in strong boundary currents, these drifters would be fixed with GPS and report the data through Argos system. Further tests in 2009 and initial deployments of pods would be made in the CORCIII California Current study area and, within three years, sampling in more remote western boundary currents is anticipated. ***This task was funded in September '07. The development engineer to accomplish the technical parts was hired on 15 November 2007. Progress will be reported in June 2008.***

References

Niiler, P. P.: The world ocean surface circulation In *Ocean Circulation and Climate*, edited by G. Siedler, J. Church and J. Gould, Academic Press, pp. 193-204. (2001)

Task E: Modelling and assimilation of future CORC data in the California Current (B. Cornuelle)

We have been working on technical details necessary to enable the California Current System (CCS) state estimation for hindcasts. This is a challenging problem, due to the relatively low density of observations compared to space and time scales. We are finishing the conversion to a new version of the ECCO code (which is the assimilation package including the MITgcm). The new version has many new features, and some of our old procedures have to be changed to work in the new system.

For example, the new assimilation system uses a "bulk formula" approach in which the control variables are atmospheric fields (such as wind, surface temperature, incoming short wave, and precipitation) as opposed to the old forcing fields (such as wind stress and heat flux). The atmospheric fields are converted to forcing using bulk formulas, which can then include the effects of small-scale structure in the ocean sea surface temperature, for example.

We have also been assembling constraints for the model initial and boundary conditions. In the long runs (1 year or greater) that we have used in the past, the initial conditions are not important relative to the forcing fields. In shorter runs, which are expected to be necessary in the CCS, it is helpful to constrain the initial and boundary conditions to be consistent with prior observations, in particular T-S relations and quasi-geostrophic balance. The constraints are being constructed from prior observations, mainly CalCOFI and other historical stations in the region, but work still needs

to be done to make the constraints part of the assimilation system and ready for the adjoint compiler. This work will also help set error bars on observations and forcing fields which are needed for best performance of the state estimation.

Finally, statistical investigations into the relation between the CCS and climate indices (PDO, ENSO, NPI) has begun, using the Optimal Interpolation technique, which is the same as the linear inverse model (LIM) formalism used in linear climate forecasting. The sea surface height (SSH) dataset from AVISO is valuable for creating indices of eddy kinetic energy (EKE) and CCS strength to be used in combination with the global climate indices and the more local CCS measures like upwelling index.